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QUANTITATIVE ASSESSMENT OF ECO-ENVIRONMENT VULNERABILITY IN KARST REGION

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ABSTRACT: The Karst area is typical eco-environmental vulnerable area, where insufficient farmland and serious soil degeneration offer vulnerable ability to endure the natural disasters. Consequently, vulnerable eco-environment can't coordinate with rapid social economic development, which leads to its feeble sustainable developmental ability. The Karst area of Chongqing in China as a study case , this paper sets up 13 influencing factors of eco-environment vulnerability to be assessment indexes, including earth surface of carbonate rock salt, area of mountainous region, area of slopping upland farming, degree of rock desertification (classified by gently, moderately, seriously), forest coverage, loss area of water and soil, soil erosion modulus, slip volume density, cultivation index, farmland area per capita, agriculture population density. Subsequently, the paper uses analytic hierarchy process (AHP) to endow indexes weight, and proposes an assessment model by using fuzzy mathematics method to analyze and assess the eco-environment vulnerability of Karst area. Finally, the assessment results are rankly divided. Results indicate: there are 3 potentially vulnerable counties, 10 gently vulnerable counties, 6 moderately vulnerable counties and 6 seriously vulnerable counties among the 25 Karst counties in Chongqing.

Keywords: Karst counties, eco-environment vulnerability, fuzzy mathematics, Chongqing.

INTRODUCTION

China is one of most growing countries of the world Karst landform (Yuan 1989; Wang 2004; Su 2002). Total area of national Karst reaches to 1.37 million km2, it approximately occupies 1/7 of total national territory area; as far as the buried limestone is concerned, the area reaches to 2 million km2 and it approximately occupies 1/5 of national territory total area. West south Karst area, that takes Guizhou Province as center and mainly spreads over Yunnan, Guizhou, Guangxi, Sichuan and Chongqing, is approximately 550,000 km^2, occupying 15.97% of national Karst area. It's one of the biggest and most intensely growing areas of Karst around global Karst pieces (Li 2002). Meanwhile, the total population is beyond 3.9 billion in the area, nearly 1/2 of national impoverished population musters reside in the region, so it's a main impoverished area in China. The restoration and reconstruction of degeneration Karst ecosystem have always been key points to which government management and scientific researchers have paid more attention (Gogu et al. 2000; Weltzin and McPherson 2000; Enrico and Laura 2002). In recent years, information technology has played a more and more important role in environment protection fields. Spatial information technology, especially GIS, has become a more significant instrument for environment management and analysis in scientific researches. At present, GIS technology has been widely applied in natural resources management and eco-environment assessment (Li et al. 2007; Oh 2001; Van and Wiedemann 2003; Lubos et al. 2006; Stevens et al. 2007; Christina and Klaus 2004; Matejicek et al. 2003; Arampatzis et al. 2004; Wu, 2002; Ron and Jakka 2003). Undoubtly, GIS-based researches on Chinese Karst eco-environmental are worthwhile and representative. But previous research focuses mainly concentrated on the Karst areas in Guizhou, Yunnan and Guangxi province (Zhang et al. 2004; Qin et al. 2005; Chen et al. 2001). For Chongqing Karst, only preliminary studies on restoration and reconstruction of degenerating Karst ecosystem were presented (Li 2004; Wang et al. 2003; Guan and Su 2006). This paper picks up 25 Karst counties of Chongqing as the examples, and applies quantity classification method to establish an assessment index system by reasonably selecting ecological environmental frailty influencing factors. In the index system, indexes are endowed weight by analytic hierarchy process (AHP) (Fahmy 2001); then, an assessment model is established by fuzzy mathematical

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generalization (Burrough 1987; Borrego 2006; Cheng 2004); finally, GIS-based rank division is accomplished. The present work is orientated to explore quantitative assessment method of ecological environment frailty of Karst area in Chongqing and rank the ecological environment frailty, provide the basis for restoration and reconstruction of degeneration Karst ecosystem, utilization of land structure optimization in Chongqing. More importantly, proposed methodology of GIS application, AHP and fuzzy mathematical generalization in eco-environmental vulnerability assessment has conmmon sense and expansibility for other study cases.

STUDY AREA

The Chongqing Karst area (containing carbonate rocks clamp detritus petrographic area)is about 41,400 km^2, accounting for 51% of the whole rural area, it mainly disseminates in Nanan, Banan, Beibei, Yubei, WanSheng, Qijiang, Nanchuan, Jiangjin, Yongchuan, Chengkou, Wuxi,Wushan, Zhongxian, Yunyang, WanZhou,Shizhu, Fengdu, Fengjie, Fuling,Wu Long, Pengshui, Qianjiang, Yongyang, Xiushan, Kaixian (Fig.1). Similar to Mediterranean Sea, it belongs to subtropics exposed dissolved Karst landscape with Karst marshland - mound peak corroded -erosion, which is characteristic of Karst marshland, funnel and Karst knoll, low-middle Mountain. In the pure stratum (entirety is phenol salt crag area), the Karst is foliation distribution, its growth is positive; in the inter-bedded stratum, Karst often takes on the belt-shaped distribution; in the m-stratum, the Karst distribution only appears several isolated bands or fragments. Within urban area, land resource in limestone mountainous area is primarily stone hillside.

ASSESSMENT METHOD

Elaborating the Assessment Index

The Karst environment is a unique ecological environment system, where energy circulation and variation of carbon matter are extremely intense and prompt (Su et al. 2002). The system has a series of ecological frailty characteristics, including low environmental capacity, small creature amount, high variation sensitivity of ecosystem, weak ability of anti-interference, inferior stability. Karst environment vulnerability are so sophisticated that it’s necessary to establish a unified assessment index system for quantizing the vulnerability degree of different Karst areas, then one would have a whole objective understanding and assessment for the integral Karst ecological environment frailty. As mentioned above, the paper initiating from natural disturbance and human disturbance of Chongqing Karst area, takes 13 influencing factors as assessment indexes, which consists of earth surface of carbonate rock salt, area of mountainous region, area of sloping upland farming, degree of rock desertification(classified by gently, moderately, seriously), forest coverage, loss area of water and soil, soil erosion modulus, slip volume density, cultivation index, per capita farmland area, density of agriculture population, to establish an assessment index system(shown in Fig.2). Current value of assessment index of eco-environment vulnerability of 25 Karst counties in Chongqing is shown in table1.

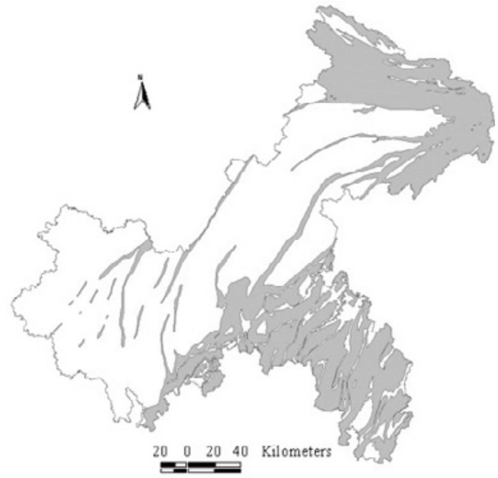

Fig. 1 A map of study area

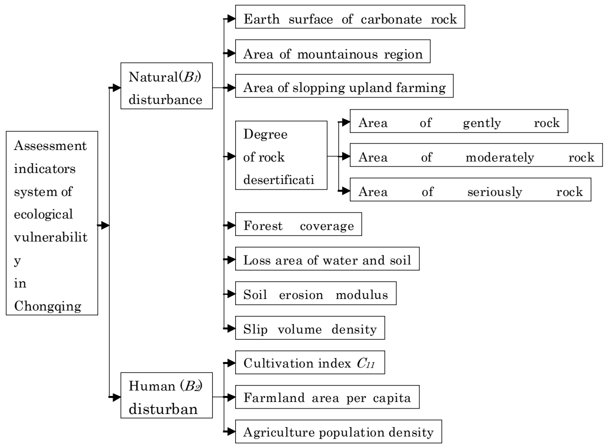

Fig. 2 Assessment indexs system of ecological vulnerability in Chongqing Karst Areas

Natural disturbance

(1) Earth surface of carbonate rock salt. The soil-forming process of carbonate rock salt is slow, usually it takes 2,500-8,500a to form 1cm thickness of soil, which

Table 1 Current value of assessment indicators of eco-environment vulnerability of 25 Karst counties in Chongqing

Karst counties	Earth surface of carbonate rock salt (X1)	Area of mountainous region (X2)	Area of sloping upland farming (X3)	Degree of gently rock desertification (X4)	Degree of moderately rock desertification (X5)	Degree of seriously rock desertification (X6)	Forest coverage (X7)	Loss area of water and soil (X8)	Soil erosion modulus (X9)	Slip volume density (X10)	Cultivation index (X11)	Per capita farmland area (X12)	Density of agriculture population (X13)
Nan'an	5.24	34.09	20.3	0.84	1.06	0.62	13.7	40.31	2893	1.09	67.49	0.59	430
Beibei	6.55	41.22	16.8	2.08	6.31	4.99	18.5	47.42	4634	1.63	67.04	1.19	467
Yubei	13.51	44.37	48	0.35	6.63	2.26	11.1	58.42	4130	1.6	75.39	2.03	382
Bannan	11.39	40.24	7.7	0.11	4.59	0.96	15.7	61.51	2695	0.78	78.92	2.52	330
Wangsheng	46	85.88	14．9	0.79	17.05	10.48	35	59.88	3108	3.27	46.08	1.45	258
Qijiang	16.56	76.38	20.2	0.63	1.06	1.03	17.4	62.50	4092	2.68	54.83	1.89	340
Nanchuan	64.4	75.71	14.4	2.39	19.31	10.66	32.9	62.12	4081	0.41	31.82	1.93	211
Jiangjin	1.83	31.02	11.1	0.07	2.27	0.08	21.2	53.79	3421	3.57	47.35	1.56	340
Yongchuan	0.92	16.44	13.8	0.02	0.76	0.05	16.54	71.05	1802	0.01	70.72	1.60	512
Wushan	38.94	92.43	28.9	5.81	35.36	41.32	31.9	76.46	3705	23.27	25.36	1.93	178
Chengkou	54.91	98.56	59.1	5.08	2.11	44.19	42	52.61	6575	0.72	23.99	5.53	62
Wuxi	92.1	90.75	55.4	2.94	25.2	41.9	32.6	51.86	6516	0.98	27.04	3.23	126
Zhongxian	0.65	54.17	39.8	0.01	1.23	0.82	15.6	79.46	3761	15.41	60.61	2.05	380
Yunyang	9.4	86.56	64.5	0.58	6.97	9.95	23.9	83.5	4426	15.69	41.54	1.79	313
Wanzhou	6.08	68.80	41.3	1.08	5.31	4.99	14.8	76.29	5054	32.16	52.2	1.61	359
Shizhu	28.55	75.08	22.1	1.51	9.94	7.64	27.19	77.47	3807	7.61	33.64	3.00	147
Fengdu	33.38	76.55	10.8	0.82	15.45	10.31	20.8	66.06	4088	15.72	46.83	2.63	267
Fengjie	45.75	90.36	28.5	5.08	26.16	24.52	24.9	69.49	5110	24.75	28.33	1.77	220
Fuling	28.17	51.28	10.1	0.69	15.59	5.82	21.2	64.88	4443	6.02	48.45	1.93	275
Wulong	84.44	91.05	16.6	9.42	26.65	23.45	31.5	66.98	4798	9.95	28.51	3.14	119
Pengshui	99.64	91.84	48.4	5.81	35.39	20.69	23.7	70.04	4811	0.2	29.45	2.77	145
Qianjiang	97.86	91.42	67.8	1.75	18.05	10.59	17.8	78.95	4517	1.95	28.04	2.09	179
Yongyang	99.25	90.53	20.9	6.35	33.63	12.5	20.2	46.04	4497	3	23.89	2.53	131
Xiushan	88.02	76.17	76.4	5.25	26.53	13.4	22.7	56.5	4391	0.24	27.94	1.42	219
Kaixian	19.87	69.96	43.3	0.83	10.45	13.35	20.8	68.14	5505	14.07	42.92	1.70	345

results in that the soil layer is thin, ground cover is discontinuous and natural soil fertility is low. In Chongqing, carbonate is mainly composed of limestone class, limestone-dolomite class and dolomite class, among them marls class only accounts for a small proportion. The speed of soil-forming is so slow that soil layer is in negative growth condition, crag body is exposed, and tendency of rocky mountain wilderness is aggravated.

(2) Area of mountainous region. Chongqing is situated at intersect zone of three big tectonic elements (Dabashan fault belt, eastern Sichuan Foldbelt and build-up Foldbelt among Sichuan, Hubei, Hunan and Guizhou Province). Its landform is primarily mountain and knoll, approximately occupying 92% of total area, where hypsography is big, undercut corrosion of rivers is intensely, soil erosion is serious, geological disasters are frequent.

(3) Area of slopping upland farming. Among the slopping upland framings, those that slopping angle is beyond 15 degree account for 48.2% in Chongqing, and those that slopping angle is beyond 25 degree account for 16.1%. The steep slope cultivation causes that soil erosion is aggravated, landslide and mud-rock flow frequently occur, ecological environment becomes more frailly.

(4) Degree of rock desertification. Distribution scope of desertification-sensitive area in Chongqing is basically consistent with limestone mountainous region. In these areas, topographic relief is big, slope is high and precipitous, vegetation coverage is low, and soil layer is thin. In some of areas, there appears massive exposed limestone, and desertification sensitivity is higher. Desertification area above moderate level reaches to 23771km^2 in Chongqing, it accounts for 30% of total rural area. The assessment endows power value to different desertification degree divided by mild, moderate and highly, to reflect the ecological environment frailty.

(5) Soil erosion modulus. There exists a big steep slope farming proportion in Chongqing Karst area; it also belongs to straight plowing. Soil erosion mainly

Table 2 Grading standard for assessment indexes of ecological vulnerability in Chongqing Karst Areas

Factors	Index Numbers	Vulnerable grades				
		Potentially Vulnerable I	Gently Vulnerable II	Moderately Vulnerable III	Seriously Vulnerable IV	Extremely Vulnerable V
Natural disturbance	C_1	10.55	30.35	50.15	69.95	89.74
	C_2	24.65	41.07	57.49	73.91	90.33
	C_3	14.57	28.31	42.05	55.79	69.53
	C_4	0.91	2.83	4.71	6.59	8.47
	C_5	4.22	11.15	18.08	25.01	31.94
	C_6	4.45	13.28	22.11	30.94	39.77
	C_7	38.91	32.73	26.55	20.37	14.19
	C_8	44.63	53.27	61.91	70.55	79.19
	C_9	2279.3	3233.9	4188.5	5143.1	6097.7
	C_{10}	3.23	9.66	16.09	22.52	28.95
Human disturbance	C_{11}	29.48	40.47	51.45	62.44	73.43
	C_{12}	5.04	4.05	3.06	2.07	1.08
	C_{13}	107	197	287	377	467

appears on the slope arid land beyond 25 degree and bare rock gravel; composite indices of soil erosion are highest in Yunyang and Qianjing counties. Analysis report on present situation of soil erosion and dynamic change in Chongqing demonstrates that soil erosion sensitivity is severe; area above moderate sensitivity is 49119.41km^2 which accounts for 59.71% of total rural area.

(6) Slip volume density. In Chongqing, geologic structure is complex, Foldbelt is intense, stratum is diverse, distribution of weak crag group is wide, mechanical difference of rock is big, Karst growth is intense, and additionally raining is abundantly. As a result, all kind of geological disasters (landslide, avalanche, mud-rock flow, Karst and so on) frequently occur, and total volume is approximately 3 billion m^3, among them distribution of landslide is most widespread. Therefore, slip volume density is an effective assessment index.

(7) Loss area of water and soil. In Chongqing, loss area of water and soil is approximately 52130.27km^2, it occupies 63.26% of total city breadth area. It mainly occurs in purple ochre and soil distribution area of purple crag parent material growth, secondly in limestone regions of spreading the yellow soil, yellow-red soil, brunisolic soil. In this region, loss of water and soil gets serious due to the existence of cliffed terrain, purple sandstone with badly resistance to weathering and corrosion and easily runoff Limestone Mountain

(8) Forest coverage. Vegetation has characteristics of calciphile, xerophytic and lithophilic in Chongqing Karst area. That vegetation growing is slow, suitable tree species is few, community structure is simply, forward succession is difficult while reversal succession is easy, results in that local vegetation coverage is lower. Furthermore, function of forest vegetation adjusting surface runoff is reduced since the forest vegetation is lacking. For example, forest coverage is 23.3% in the 1950s in Shizhu County, 11.3% in the 1970s, 10.97% in the1980s.

Human disturbance

The ecological environment of Karst area is a frail environment susceptibly restricted by the humanity activity, where land resource suitable for farming is insufficient, ability of bearing natural disasters is weak, land quality is bad, inevitably, and population supporting capacity is low. As growth of population and overload of land, agriculture ecological environment is increasingly serious due to long-term irregular cutting, cultivation on the deep slope and excessive reclamation. In 2003, agricultural cultivated area is 13,532 km^2 in Chongqing, dropping 17% compared to 1997, per capita cultivated area is reduced to 0.65 acre which occupies 45% of national average level. Per capita cultivated area is 0.15 acre lower than warning line of United Nations organization. High agricultural population and small per capita cultivated area lead to that land load is oversized, a vicious circulation which successively involves excessive reclamation, soil degeneration, impoverished economy, and further excessive reclamation, is formed. Therefore, cultivation index, farmland area per capita and agriculture population density are selected.

Assessment Standard

At present, there is no unified classification standard and assessment basis for ecological environment frailty of Karst area (Jing et al. 2003; Tian et al. 2005). The paper divides frailty rank of indexes into 5 frailty ranks (potentially frail, gently frail, moderate frail, seriously frail, extreme frail) according to D-value division between maximum value and minimum value of each index (Table 1). Assessment standard includes forward-index (bigger the index value is, bigger the frailly is) and negative-index (smaller the index value is, bigger the frailly is). Forward-index standard adopts the value attained by adding minimum value of each index to half of D-value division as standard value of potentially frailty, and adopts the value attained by minimum value of each index minus half D-value division as limited value of extremely frailty, the middle three ranks are equidistantly defined between the two attained values; negative-index goes reverse (shown in Table 2).

Assessment Model

Endow index weight

Because various indexes play different roles in the index system, their influencing extents to ecological environment are discriminative. And weighting assessment method is usually utilized to definite the influence discrepancy. At present, a lot of researches on weight definite question have been carried on, among them weight is defined according to either researcher's experience and subjective judgment or all kinds of mathematics methods (Li et al. 2004; Xiao et al. 2005). This paper uses analytic hierarchy process (AHP) to determine index weight of ecological environment frailty in Chongqing Karst. AHP is a simple systematic engineering method to quantitatively analyze non-quantitative objects. It cannot only adequately consider the researcher’s subjective judgment during the quantitative and/or qualitative analysis, but also express the complex system in a hierarchic structure from interrelation between inside and outside of the system, which contributes to make the decision-making process more systemic, numerical and modeling by analyzing step by step. Due to its ability of assigning proper weights to various factors of complex system, AHP is also called as an analytic multi-level value process. As a complex system with multi-subjects and multi-levels, eco-environment system is suitable to employ AHP (Li et al. 2007) as assessment method. The detailed analytic process is as follows.

① Establish comparison matrix B_2

Layer B is broken down into Layers C to establish the pair-wise comparison matrix. Relative importance of C_1, C_2 ..., C_{13} is analyzed by Delphi method, also so-called Expert Judgment. During the research, we invite experts in ecological fields to give the relative importance of each factor, respectively, then universally analyze all the opinions, and finally, gain the rank of relative importance for each factor. The established comparison matrix of human disturbance is seen in Table 3.

②Calculate the product of every row M_i

$$M_i = \prod_{j=1}^{m} C_{ij} \quad (=1, 2,..., m)$$

③Get the cubic root of M_i

$$\beta_i = M_i^{\frac{1}{m}}$$

④Get the weight of C_{11}, C_{12} and C_{13}

$$w_i = \frac{\beta_i}{\sum_{i=1}^{m}\beta_i} \quad (=1,2,...,m) \quad w_i = (0.1386, 0.2733, 0.5881)$$

⑤Calculate the maximum eigenvalue

$$\lambda_{\max} = \frac{1}{m}\sum_{i=1}^{m}\frac{(Bw)_i}{w_i} \quad (\lambda \max = 3.0651)$$

⑥Use *CR=CI/RI* to carry on consistent test. $CR \leq 0.10$ means that the consistence of this matrix is acceptable.

In the equation, CI $= \frac{\lambda_{\max} - n}{n-1}$ =0.03256, *RI* is average random consistence index. When m=3, *RI*=0.58, *CR* (random consistence index) =0.0561$\leq$0.10, weight of assessment indexes for human disturbance is acceptable (Table 4).

Similarly, weight of assessment factor for natural disturbance is gotten (Table 5).

Table 3 comparison matrix of human disturbance

B_2	C_{11}	C_{12}	C_{13}
C_{11}	1	5/9	1/3
C_{12}	9/5	1	3/5
C_{13}	3	5/3	1

Table 4 Weight of assessment indexes for human disturbance of eco-environment vulnerability (B2)

Index	C_{11}	C_{12}	C_{13}
Weight	0.1386	0.2733	0.5881

Table 5 Weight of assessment indexes for natural disturbance of eco-environment vulnerability (B1)

Index	C_1	C_2	C_3	C_4	C_5
Weight	0.182	0.046	0.136	0.023	0.068
Index	C_6	C_7	C_8	C_9	C_{10}
Weight	0.136	0.091	0.106	0.106	0.106

Calculation of eco-environment frailty

Ecological environment frailty has some fuzziness in the Karst area. That is to say, concrete ecological environment should be confirmed to be neither absolutely frail nor absolutely stable, membership relationship of varying extent is only proposed relative to some frail standard. Therefore, vulnerability assessment for Chongqing Karst area may be dealt as a fuzzy problem. Membership degree to some level frailty is mainly calculated by establishing membership function according to current value of assessment index (Table 3).

The assessment index is divided into forward-index and negative-index, their membership degree formula are different. For forward-index, its formula is as follows:

$$x_i < s_{i,1}, r_{i,1} = 1, r_{i,2} = r_{i,3} = r_{i,4} = r_{i,5} = 0\,;$$

$$s_{i,j} \le x_i \le s_{i,j+1}, r_{i,j+1} = \frac{x_i - s_{i,j}}{s_{i,j+1} - s_{i,j}},$$

$$r_{i,j} = 1 - r_{i,j+1}\,,\ (j = 1, 2, 3, 4);$$

$$x_i > s_{i,5}, r_{i,5} = 1, r_{i,1} = r_{i,2} = r_{i,3} = r_{i,4} = 0\,;$$

Calculation method of negative-index membership degree is similar to that of forward-index, its formula is as follows:

$$x_i > s_{i,1}, r_{i,5} = 1, r_{i,1} = r_{i,2} = r_{i,3} = r_{i,4} = 0\,;$$

$$s_{i,j} \ge x_i \ge s_{i,j+1}, r_{i,j+1} = \frac{x_i - s_{i,j}}{s_{i,j+1} - s_{i,j}},$$

$$r_{i,j} = 1 - r_{i,j+1}\,,\ (j = 1,\ 2,\ 3,\ 4);$$

$$x_i < s_{i,5}, r_{i,1} = 1, r_{i,2} = r_{i,3} = r_{i,4} = r_{i,5} = 0\,;$$

Using above formulas, relational matrix between assessment indexes with frailty is gotten. Then assessment model of eco-environment frailty is

$$R_{i,j} = \begin{pmatrix} r_{11}r_{12}r_{13}r_{14}r_{15} \\ r_{21}r_{22}r_{23}r_{24}r_{25} \\ \cdots\cdots\cdots\cdots\cdots \\ r_{i1}r_{i2}r_{i3}r_{i4}r_{i5} \end{pmatrix}$$

$$U_j = w_i \cdot R_{i,j}$$

In usual cases, the biggest membership degree principle is employed to analyze the fuzzy assessment result after accomplishing the assessment model, but this method has some limitations that unreasonable appraisal results would be possibly obtained if the difference among judgment objects with different rank membership degrees is not large. In order to lessen the limitation by assessment model and access the essence, the paper applies the weighted average principle for obtaining the membership rank, and analyzes result vector of fuzzy synthesis assessment.

$$B^* = \frac{\sum_{j=1}^{5} U_j^2 . j}{\sum_{j=1}^{5} U_j^2}$$

where, $r_{i,j}$ is relative membership degree of the *i*th index to *j*th level standard; x_i is current value of the *i*th index; $s_{i,j}$ is standard value of the *i*th index to *j* level frailty rank; w_i is the index weight coefficient of *i*th index; U_j is frailty of the *j*th level standard; *B** is the frailty, *j* is the frailty rank.

According to formulas of fuzzy assessment, the paper firstly carries on frailty assessment for natural disturbance and human disturbance; then, takes assessment result as assessment factor; finally, obtains

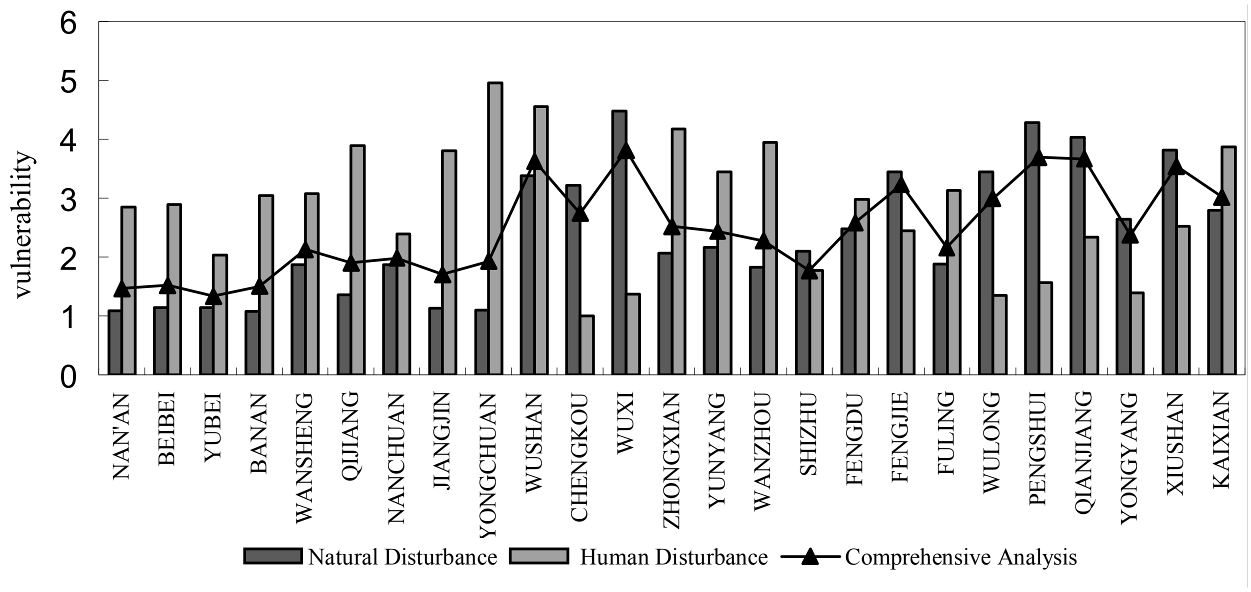

Fig. 3 Evaluation results of ecological vulnerability of 25 Karst counties in Chongqing

integrated rank division of ecological environment frailty in Chongqing 25 Karst counties (Fig.3).

GIS-based rank division

The paper applies ArcView software as assessment tool, carries on rank division according to weighted average principle (potentially vulnerable: B^*<1.5; gently vulnerable: 1.5 <=B^*<2.5; moderately vulnerable: 2.5 <= B^* < 3.5; seriously vulnerable: 3.5 <= B^*<4.5; extremely vulnerable: B^*>= 4.5). Rank divisions of natural disturbance and human disturbance are shown in Figs.4 and 5, respectively. Rank division of eco-environmental comprehensive vulnerabilities of 25 Karst counties in Chongqing is shown in Fig.6.

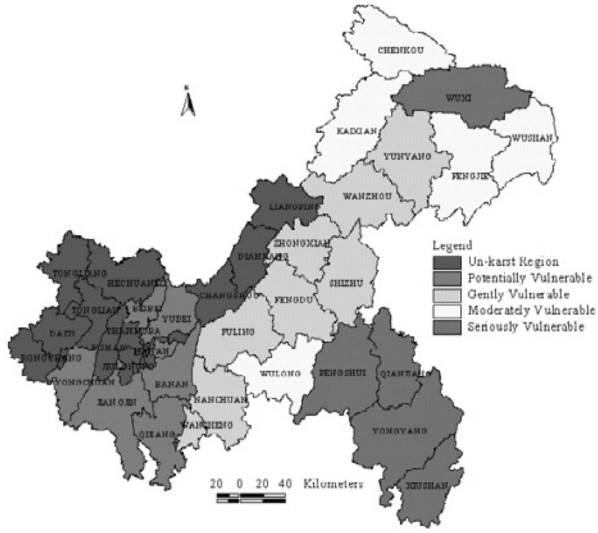

Fig. 4 Rank division figure of natural disturbance vulnerability of 25 Karst counties in Chongqing

RESULTS

The comprehensive rank division results indicate that there are 3 potentially vulnerable areas, 10 lightly vulnerable areas, 6 moderately vulnerable areas, and 6 seriously vulnerable areas in the 25 Karst areas of Chongqing.

Ⅰ Potentially vulnerable area includes 3 areas (Nanan, Yubei, and Banan). Its area is 3561.11km^2, accounting for 5.26% of total area. The region is mainly composed of cross-belt of city and countryside, where rural ecosystem and agricultural ecosystem are coexisted, natural environmental condition is relatively superior, earth surface of carbonate rock salt is slight (<13.51%), statuses of forest and vegetation are better, peasant's income is stable, development level of economy is higher. However, runoff of ground surface is rich, intensity of rain is big, soil erosion is serious (area > 40.31%), soil erosion (modulus >3239.33t/ km^2.a) is moderate, the geological disasters frequently occur (primarily landslide and danger crag), so it belongs to potentially vulnerable area.

Ⅱ Gently vulnerable area includes 10 areas (Beibei, Qijiang, Jiangjin, Yongchuan, Wan Sheng, Nanchuan, Shizhu, Yunyang, Fuling and Wanzhou), the area is 23931.04km^2, accounting for 35.34% of total area. In this region, natural environmental condition is better, forest coverage is higher, and it has the obvious function of self-control water source and accumulation and regulation of hydrology. However, mountainous area is big, rainfall is big and centralized, and soil erosion is serious. In addition, the humanity activity is frequent, index of cultivation is higher, and land reserve resource is insufficient. So this region belongs to mild vulnerability.

Ⅲ Moderately vulnerable area includes 6 areas (Fengjie, Kaixian, Zhongxian, Chengkou, Fengdu and Wu Long),

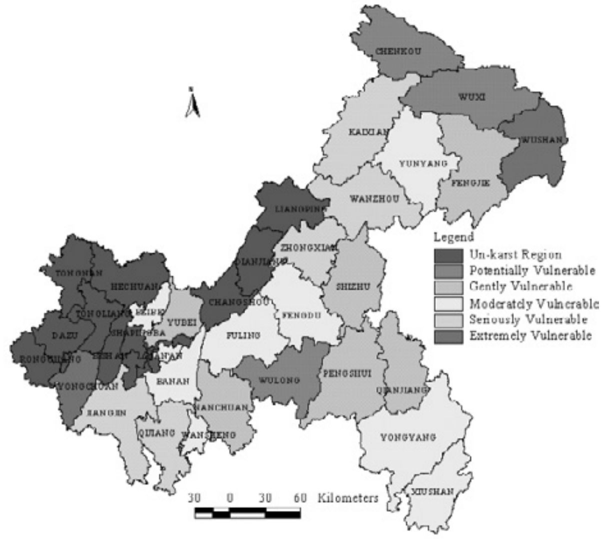

Fig. 5 Rank division figure of human disturbance vulnerability of 25 Karst counties in Chongqing

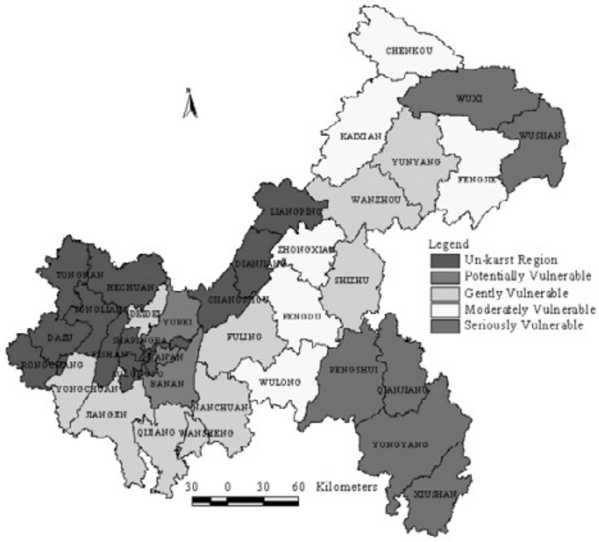

Fig. 6 Rank division figure of eco-environmental comprehensive vulnerability of 25 Karst counties

its area is 19, 318 km^2, accounting for 28.52% of total area. In this region, geologic structure is complex, slope stability is bad, landslide risk is big (landslide bulk density >134,800 m^3/km^2). And, intensity of soil corrosion is high (average mold is 4,973 t/ km^2.a), soil layer is superficial, land productive is low, chemical fertilizer is emphasized instead of organic fertilizer, agriculture strongly depends on chemical fertilizer, agricultural pollution is serious, potential harm to environment is big; also, drought and flood disasters are frequent, agricultural production is extremely unstable, economical development is slower. So this region belongs to moderate vulnerability.

Ⅳ Seriously vulnerable area includes 6 areas (Pengshui, Wushan, Wuxi, Qianjiang, Yongyang, Xiushan), its area is 20,911 km^2, accounting for 30.88% of total area. In this region, middle-low mountain area occupies above 96% of breadth area, earth surface of carbonate rock salt is large (> 50%), especially above 90% in Wuxi, Qianjiang and Yongyang. Forest coverage is low, biodiversity is reduced, soil erosion area is broad (> 63.08%). The soil is mainly composed of yellow soil and calcareous soil, rainstorm runoff is seriously due to big slope and centralized rain, it belongs to intensively erosion area (modulus >4739t/km^2.a). The land desertification is serious; land area above moderate sensitivity accounts for 53%, highly sensitive area approximately occupies 23.4%. Moreover, topography is rugged, transportation is unenlightened, contradiction of human-land is serious, particularly proportion of dry slope farming is big (> 44.07%), economy is backward. So this region belongs to serious vulnerability.

CONCLUSIONS

(1)The paper takes 25 Karsts areas in Chongqing as examples, sets up a set of comprehensive and scientific index system by reasonably selecting influence factors of ecological environmental frailty of Karst area, defines an objective and accurate graduation standard, and uses analytic hierarchy process method(AHP) to quantize weight of each index, then establishes fuzzy mathematical assessment model, constructs judgment matrix, finally, carries on frailty rank division based on the GIS technology. It provides a reference for restoration and reconstruction of degeneration Karst ecosystem and optimization of land utilization structure in Chongqing.

(2)The paper carries on quantitative assessment for ecological environments of 25 Karst counties in Chongqing using suggested index system and assessment method, ecological environmental vulnerability is relatively divided into four gradations. There are 3 potentially vulnerable counties, 10 gently vulnerable counties, 6 moderately vulnerable counties and 6 seriously vulnerable counties. The assessment results basically conform to actual situation of ecological environment vulnerability in Chongqing Karst. In addition, assessment method for ecological environment vulnerability of Karst area is reasonable and feasible.

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